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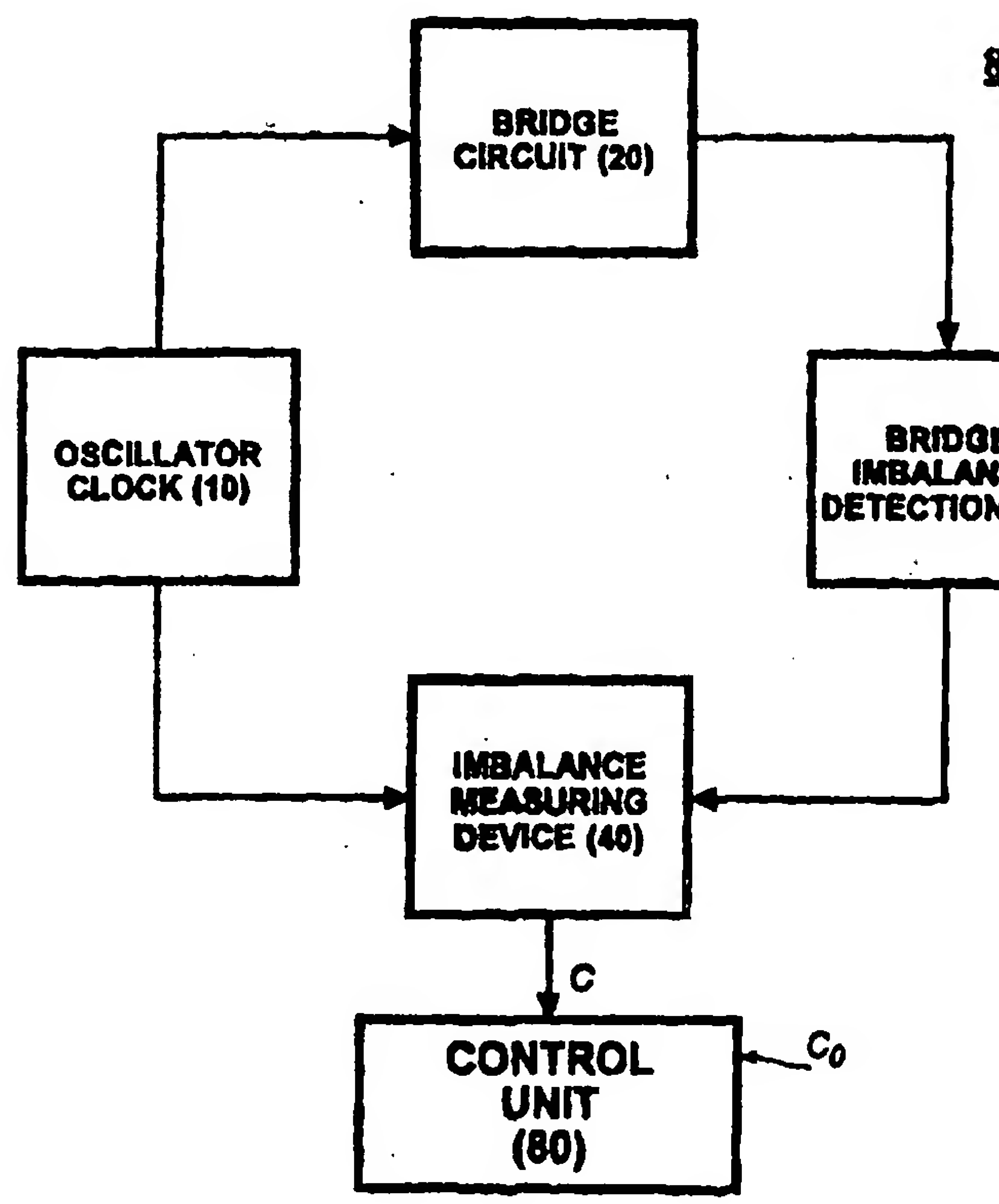
(54) Title: PHASE SHIFT DETECTION AND MEASUREMENT CIRCUIT FOR CAPACITIVE SENSOR

(57) Abstract

A capacitor measurement and detection circuit (8) for monitoring changes in a sensor capacitor, comprising: a bridge circuit (20) including a reference capacitor (400) and the sensor capacitor (100) for generating output signals (510, 520) indicative of the difference between the magnitude of the reference and sensor capacitors; a fixed frequency oscillator (10) connected to the bridge circuit for driving the bridge circuit at a fixed frequency; a bridge imbalance detector (30) responsive to the output of the bridge circuit for generating conditioned signals; a counter driven by the oscillator (10) and responsive to the output signals of the detector (30) for generating an output signal indicative of the phase difference between the reference arm of the bridge circuit and the active arm of the bridge circuit, thereby providing an indication that an object is positioned in the electric field created by the sensor (50).



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Phase Shift Detection and Measurement Circuit For Capacitive Sensor

The present invention is generally related to a circuit for driving and measuring the change in capacitance of a capacitive sensor and more particularly a reflective or driven shield capacitive sensor.

United States Patents 5,166,679 and 5,442,347 show two examples of multi-element reflective capacitive sensors. United States Patents 5,166,679 discusses a circuit in general terms which will detect a change in capacitance and send a corresponding control signal and 5,442,347 describes several standard circuits which are used for measuring an imbalance in bridge circuits.

It is an object of the present invention to provide an improved circuit and methodology for measuring a change in magnitude of a capacitive sensor. It is another object of the present invention to provide a circuit that is stable and immune to changes in temperature and humidity. The present invention provides an improvement over the prior art by providing a digital phase detection and measurement means. The digital phase detection and measurement circuit of the present invention is superior to other methods because it is more stable and accurate, provides a quicker response time and is easier to implement. Other detection and measurement methods include an analog phase or amplitude comparison of the excitation oscillation across the reference and active arms of the bridge circuit. This method has the following inherent problems: (1) Phase comparison - both oscillations have to have the same amplitude in order to make an accurate measurement of the phase shift; this is virtually impossible to accomplish due to component

tolerances. Additionally, changes in sensor capacitance will adversely affect signal amplitude requiring additional compensation circuitry to provide an accurate phase shift measurement. (2) Small signal-to-noise ratio - the usable signal in an analog phase measurement system will be relatively the same size as the total overall noise. Required amplification of the signal will result in excessive noise. Any attempt to filter this noise will result in a slower response time. (3) Thermal Instability - the analog circuitry necessary to implement a phase detector (resistors, capacitors, operational amplifiers) performance will be affected by temperature. This will cause unpredictable circuit response to similar inputs at different temperatures. Additional components required to compensate for thermal effects would increase circuit complexity.

The digital phase detection means starts with a high speed crystal oscillator which drives a digital counter. The use of a digital counter is advantageous as it enables the determination of the magnitude of an imbalance in the bridge without the need to filter the analog output of the bridge circuit (as done in the prior art), thereby providing a more responsive circuit. The high speed crystal oscillator frequency is then divided down to a fixed frequency at which it drives a voltage level shifter circuit. The voltage level shifter circuit in turn powers the bridge at this lower frequency but at a higher voltage. This technique essentially keeps the voltage level shifter circuit in sync with the counter. This approach eliminates the effects of possible phase drift between the bridge circuit and the counter circuit ensuring circuit stability. Also the use of comparators, which sense a zero crossing, enhances the performance and accuracy of

the circuit by responding very quickly to the change in phase of the square wave input.

Accordingly, the invention comprises: a capacitor measurement and detection circuit for monitoring changes in a sensor capacitor, comprising: a bridge circuit including a reference capacitor and the sensor capacitor for generating output signals indicative of the difference between the magnitude of the reference and sensor capacitors; a fixed frequency oscillator connected to the bridge circuit for driving the bridge circuit at a fixed frequency; a bridge imbalance detector responsive to the output of the bridge circuit for generating conditioned signals; a counter driven by the oscillator and responsive to the output signals of the detector for generating an output signal indicative of the phase difference between the reference arm of the bridge circuit and the active arm of the bridge circuit, thereby providing an indication that an object is positioned in the electric field created by the sensor.

Many other objects and purposes of the invention will be clear from the following detailed description of the drawings.

Brief Description of the Drawings

In the drawings:

FIGURE 1 is a block diagram showing many of the major components of the present invention.

FIGURE 2 is a circuit diagram of a bridge circuit.

FIGURE 3 illustrates a five (5) plate (electrode) reflective capacitive sensor.

FIGURE 4 shows the details of a bridge imbalance detector.

FIGURE 5 is a timing diagram illustrating certain system signals.

Detailed Description of the Drawings

FIGURE 1 shows a detection and measuring circuit 8 comprising an oscillator 10, which provides a stable square wave reference signal, a bridge circuit 20 (also shown in FIGURE 2), a bridge imbalance detector 30 (also shown in FIGURE 4) and an imbalance measuring device (digital counter) 40. The oscillator 10 synchronously drives the bridge circuit 20 and the imbalance measuring device (digital counter) 40 at a predetermined high frequency. The output from the bridge circuit is fed into a bridge imbalance detector 30 which conditions the output signals of the bridge circuit 20 and communicates these signals to the counter 40.

Reference is briefly made to FIGUREs 2 and 3. FIGURE 2 is a more detailed diagram of the bridge circuit 20 and FIGURE 3 shows a typical reflective capacitive sensor 50. In the embodiment shown the capacitive sensor 50 is comprised of four different capacitors (100, 200, 300, 400). The bridge circuit 20 comprises resistors 110 and 120 and includes capacitors 100 (also referred to as a sensing capacitor), 200, 300,(also referred to as reflective shield capacitors) and 400 (also referred to as reference capacitor) which are formed between two respective plates or electrodes of the reflective capacitive sensor 50 (shown in FIGURE 3). The capacitive sensor 50 employs five electrodes or plates 105, 107, 109, 111 and 113. Plate 113 is a grounded plate. Plates 105 and 113 form the first or sensing capacitor 100, plates 107 and 113 form the second or first shield capacitor 200, plates 109 and 113 form the third or second shield capacitor 300 and plates 111 and 113 form the fourth or reference capacitor 400.

The bridge circuit 20 also includes operational amplifiers 130 and 140 which are used in a voltage follower configuration and act as buffers and isolate the capacitors 200 and 300 from the bridge circuit 20. Operational amplifiers 150 and 160 are also used in a voltage follower configuration and act as buffers to isolate the bridge imbalance detection device 30 from the bridge circuit 20. The output of the operational amplifiers 150 and 160, shown as signals 510 and 520 are also the output signals of the bridge circuit 20. These signals are communicated to the bridge imbalance detection circuit 30. These signals 510 and 520 are shown in FIGURE 6, lines 2 and 3.

The bridge imbalance detector 30 is shown in FIGURE 4 and includes two comparators 170 and 180. These comparators respond to a zero crossing of signals 510 and 520 received from the bridge imbalance detector 30. The comparators 170 and 180 provide a high "slew rate" square wave output signal 35 and 37 that is fed to the counter 40.

Reference is again made to FIGUREs 2 and 3. Under design conditions the reference capacitor 400 (comprising plates 111 and 113) and the sensing capacitor 100 (comprising plates 105 and 113) are designed to have the same nominal value of capacitance when the sensing field of the capacitive sensor 50, generally shown as 100F, is not disturbed by an object. As can be seen from FIGURE 3 the spacing between plate 105 and the ground plate 113 is substantially larger than the spacing between the reference capacitor plate 111 and the ground plate 113. The reference capacitor and the sensing capacitor are made equal by enlarging the size of plate 105 in proportion to its increased distance from the ground plate. FIGURE 3 also shows the position of the two shielding plates 107 and 109

which in combination with the ground plate 113 define the generally fixed value shielded capacitors 200 and 300 respectively. FIGURE 3 also shows the sense of the electric field lines of the reference capacitor 400 (shown as 400F), the shield capacitors 200 and 300 (shown as 200F, 300F). With regard to FIGURE 2, it can be seen that the output of the oscillator 10 is applied to each of the capacitors 100-400, appropriately charging and discharging the capacitors at the fixed clock frequency rate. An inspection of the bridge circuit 20 reveals that resistor 110 is smaller than resistor 120. This mismatch in resistors ensures that there will be a determinable phase shift in the output wave form from amplifier 160 as compared to the output wave form from amplifier 150, even in the situation where the magnitude of the sensing and reference capacitors 100 and 400 respectively are identical. The reason for introducing a known phase shift is to facilitate activating and de-activating the counter 40. The benefit of driving the shield capacitors 200 and 300 is as follows: reflective shield capacitor 200 reflects the electric field of sensing capacitor 100 outward thus concentrating the electric field lines in a unidirectional manner and away from the return path or ground plate 113, thus extending the range. Reflective shield capacitor 300 isolates the reference sensor capacitor 400 from objects in proximity to the sensor 50; this ensures that the only environmental changes, i.e. temperature will effect 400F.

The timing diagram of FIGURE 6 shows the output signals 510 and 520 from the operational amplifiers 150 and 160. These output signals are not pure square waves due to the exponential charge rate of the sensing capacitor 100 and reference capacitor 400. As mentioned above these output signals are

communicated to the detector 30 which generates clean square wave signals 35 and 37, at a divided down frequency of the oscillator 10.

The falling edge 1 of signal 35 is used to clear the counter 40 and cause it to hold all its bits at a low logical state. The rising edge 2 of signal 35 is used to start the counter 40. The rising edge 3 of signal 37 is used to stop the counter 40. The output of the digital counter is a count or number that directly correlates to the phase shift between the output signals 510 and 520 of the reference leg and sensor leg of the bridge 20. Line 610 of Figure 5 illustratively shows the numerical value C, of counter 40, where C_1 is representative of a count corresponding to a first distance between an object (occupant) and the sensor 50, and C_2 is illustrative of a different distance. This phase shift is directly correlatable to the difference in value between the sensing capacitor 100 and the reference (fixed value) capacitor 400.

As the electric field 100F of the sensing capacitor 100 is interfered with by an object, the value of the sensing capacitor 100 will vary, changing the phase relationship between the output signals 35 and 37 of the detector 30 correspondingly increasing or decreasing the digital count generated by the counter 40. The value of the reference capacitor 400 is invariant as it is shielded by electrode 109. The digital count is communicated to an electronic control unit 80 which subtracts, from this count, an initial count C_0 corresponding to the predetermined phase shift designed into the bridge circuit 20. This count C_0 or digital number is directly correlatable to the magnitude e of the phase difference between the reference capacitor 400 and the new capacitance value of the sensing capacitor 100 due to the introduction of an object.

If, for example, the capacitive sensor 50 were disposed within the seat of a car, a determinable change in capacitance of the sensor capacitor 100 would indicate that an occupant (as opposed to an inanimate object) is normally seated in the seat, thereby providing information to an air bag controller or controller for a seat belt pretensioner that such devices could be used to protect the occupant. Further, if a second capacitive sensor 50 were installed for example in the instrument panel on the passenger side of the vehicle (in front of the passenger) or alternatively, installed within the air bag cover covering the driver side air bag (directly in front of a driver), a measurable change in the output of the appropriate sensing capacitor 100 of these added capacitive sensors 50 would indicate that the driver or passenger, as the case may be, is substantially close to the driver side air bag or instrument panel indicating that the driver or passenger is out of position. This information can be used by the air bag controller to modify the inflation rate of the air bag to more effectively protect the out-of-position driver or passenger.

Many changes and modifications in the above described embodiment of the invention can, of course, be carried out without departing from the scope thereof. Accordingly, that scope is intended to be limited only by the scope of the appended claims.

Claims

1. A capacitor measurement and detection circuit (8) for monitoring changes in a sensor capacitor, comprising:

a bridge circuit means (20) including a reference capacitor (400) and the sensor capacitor (100) for generating output signals (510, 520) indicative of the difference between the magnitude of the reference and sensor capacitors;

a fixed frequency oscillator (10) connected to the bridge circuit for driving the bridge circuit at a fixed frequency;

a bridge imbalance detector (30) responsive to the output of the bridge circuit for generating conditioned signals;

counter means driven by the oscillator (10) and responsive to the output signals of the detector (30) for generating an output signal indicative of the phase difference between the reference arm of the bridge circuit and the active arm of the bridge circuit, thereby providing an indication that an object is positioned in the electric field created by the sensor (50).

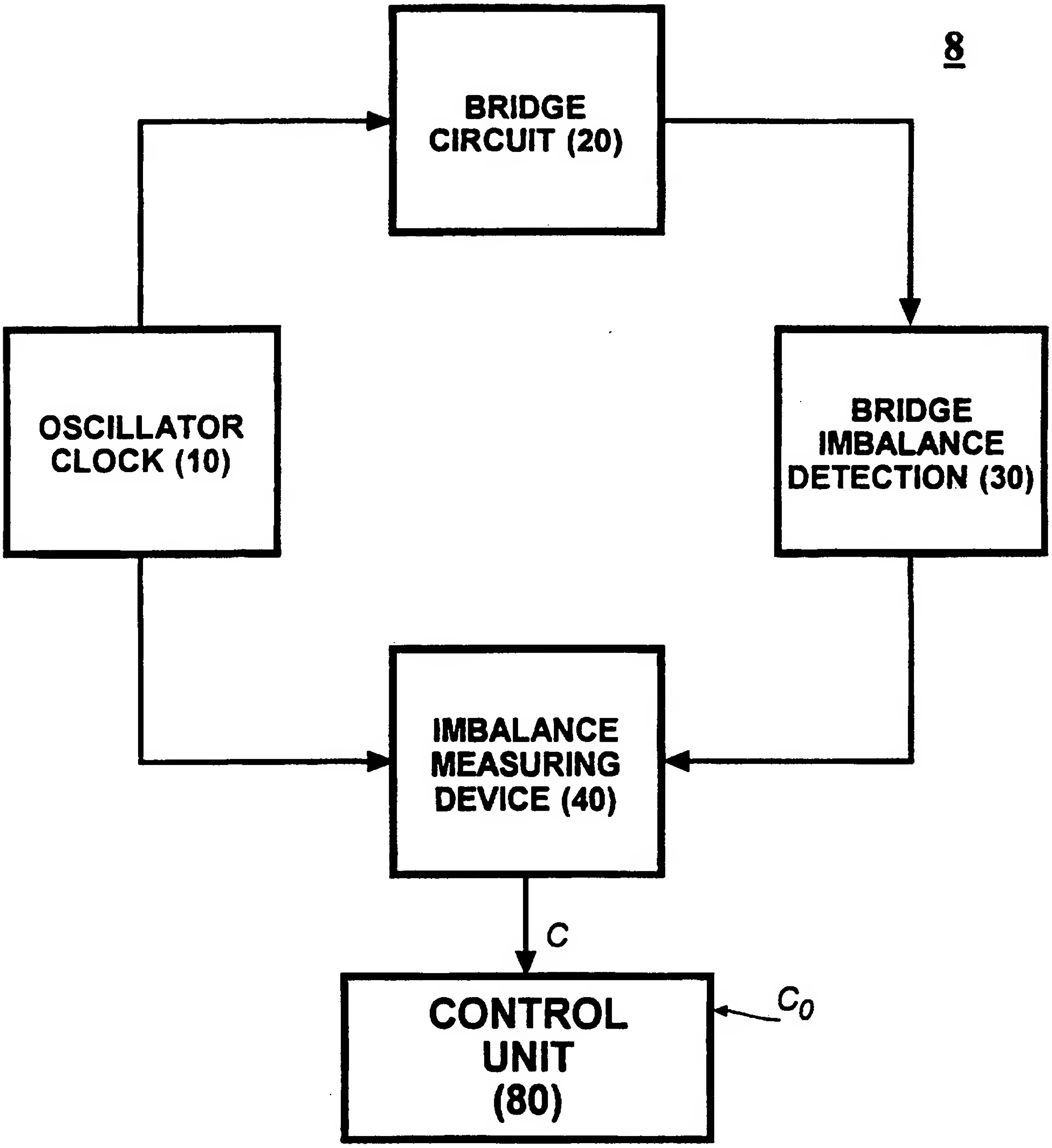
8
BRIDGE CIRCUIT (20)
OSCILLATOR CLOCK (10)
BRIDGE IMBALANCE DETECTION (30)
IMBALANCE MEASURING DEVICE (40)
C
CONTROL UNIT (80)
C_0

FIG - 1

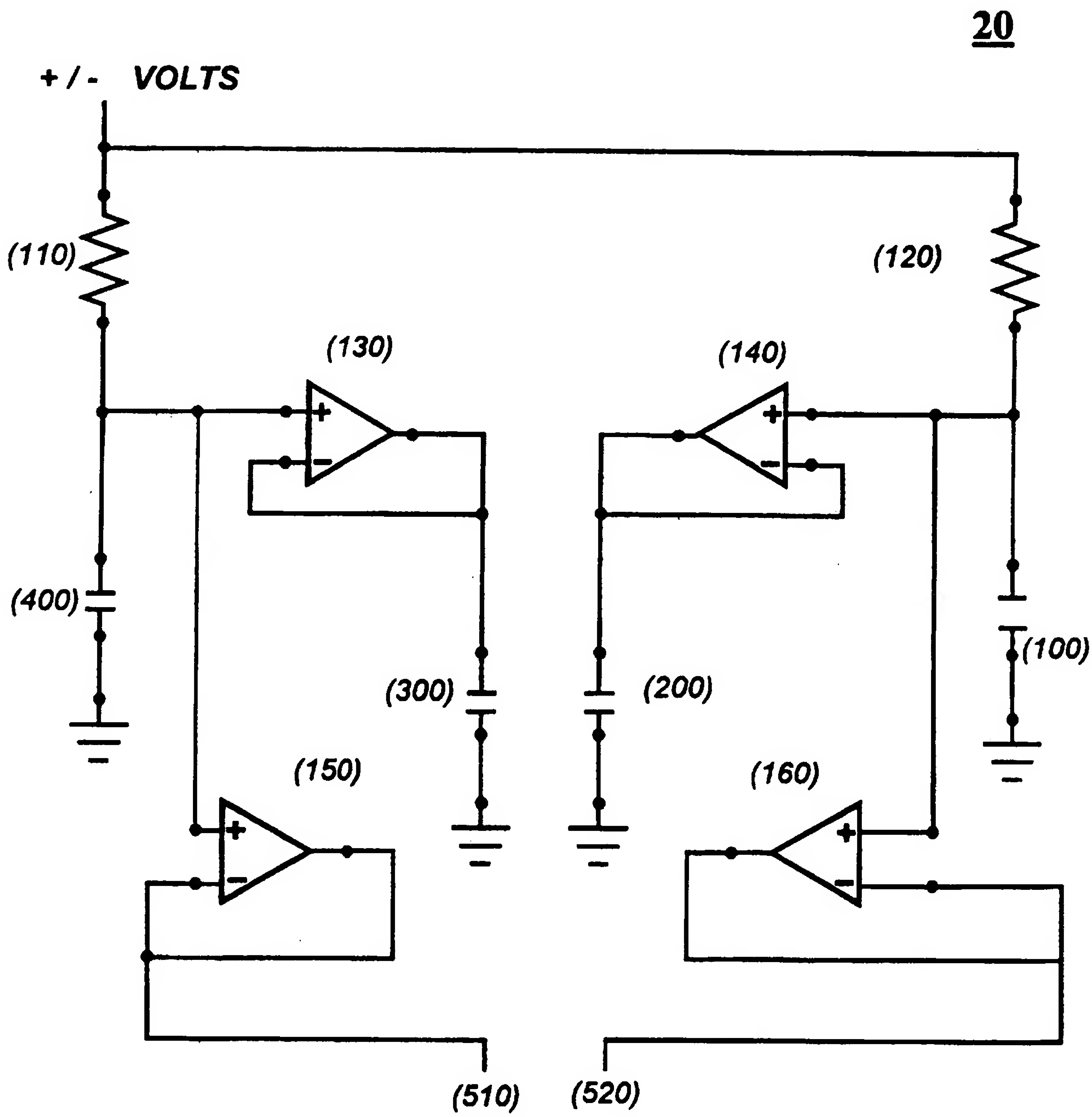

FIG. - 2

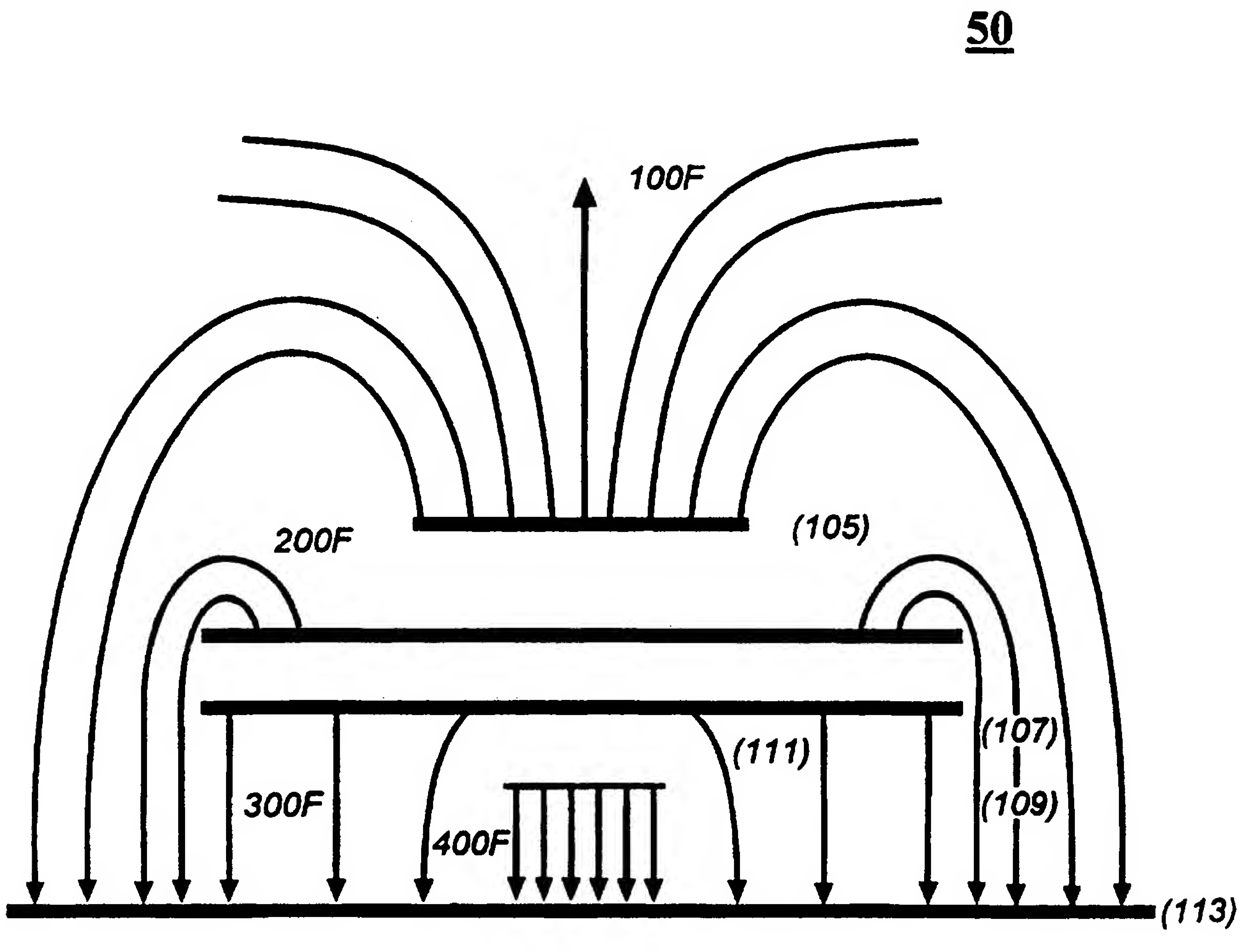

FIG. - 3

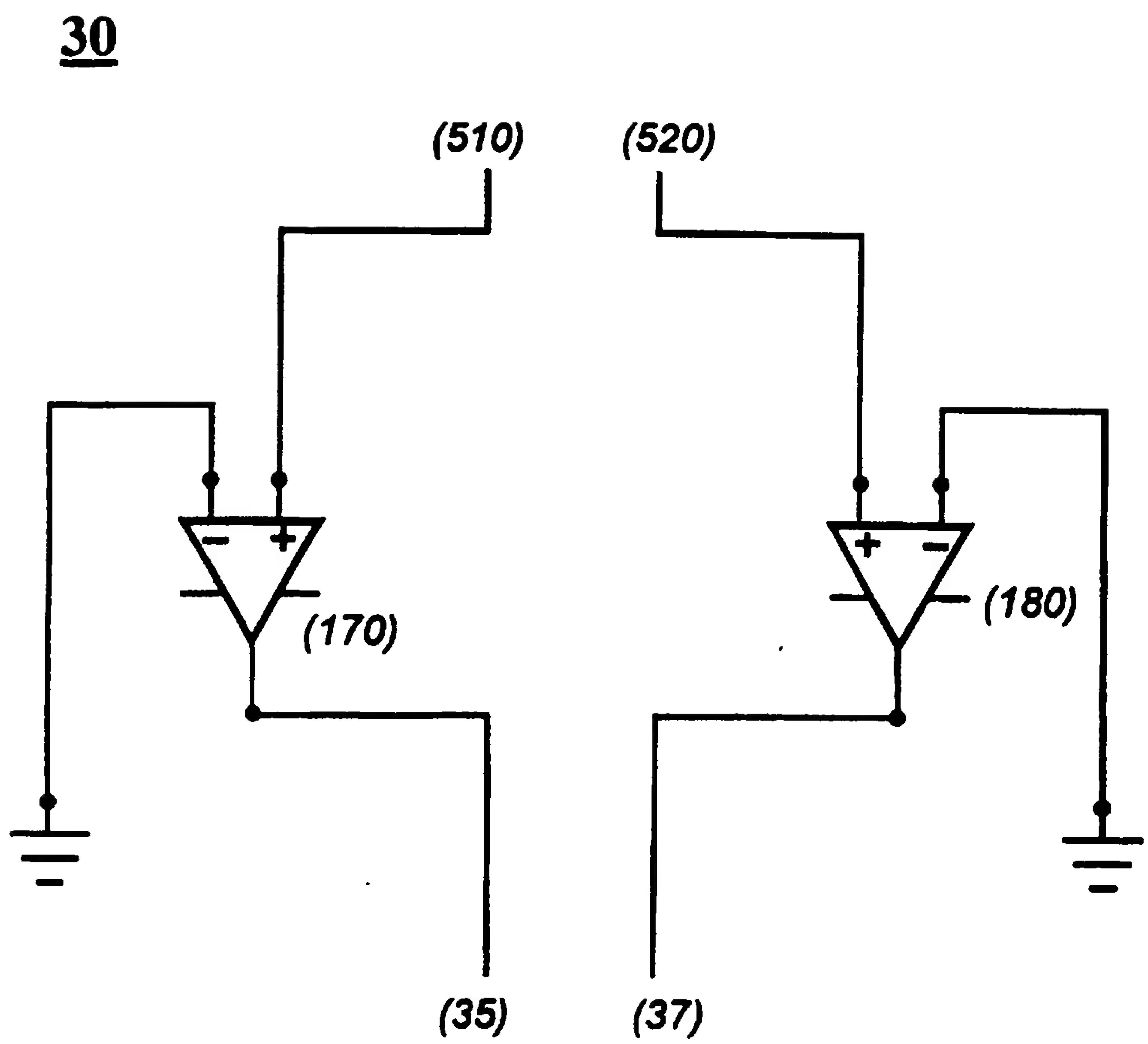

FIG. - 4

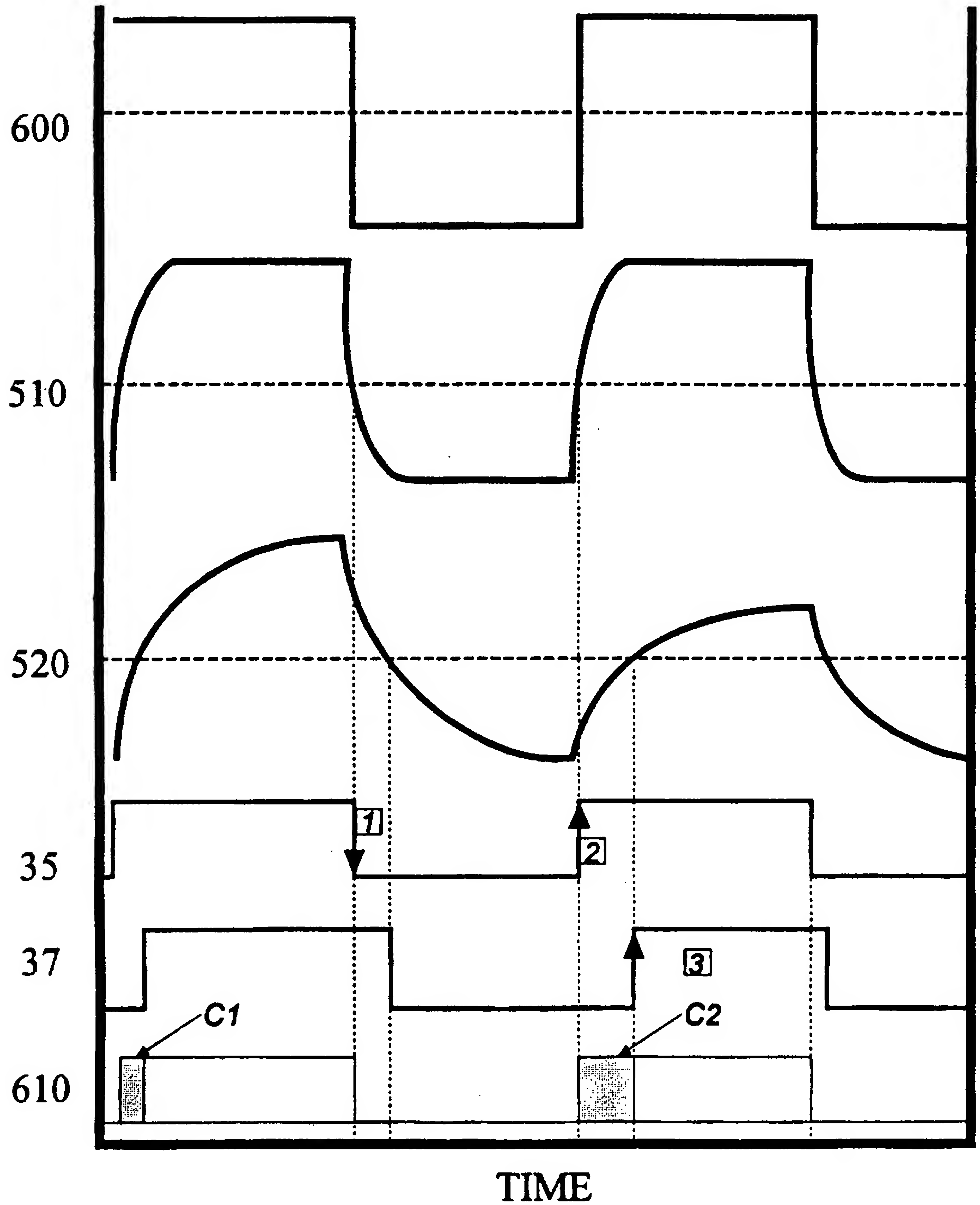

FIG. - 5

PCT/US 97/14275

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01V3/08 H03K17/955

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01V H03K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 508 700 A (TAYLOR THOMAS M ET AL) 16 April 1996 see column 9, line 7 - line 39; figure 2 ---	1
Y	US 5 442 347 A (VRANISH JOHN M) 15 August 1995 cited in the application see column 5, line 47 - line 52; figures 6,8 ---	1
A	US 5 373 245 A (VRANISH JOHN M) 13 December 1994 see figures 5B,6 ---	1
A	US 5 076 566 A (KRIEGEL JON) 31 December 1991 see column 3, line 19 - line 41; figure 3 --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of theinternational search	Date of mailing of the international search report
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 3 836 828 A (SIEGEL L) 17 September 1974 see column 2, line 35 - column 3, line 2 -----	1

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